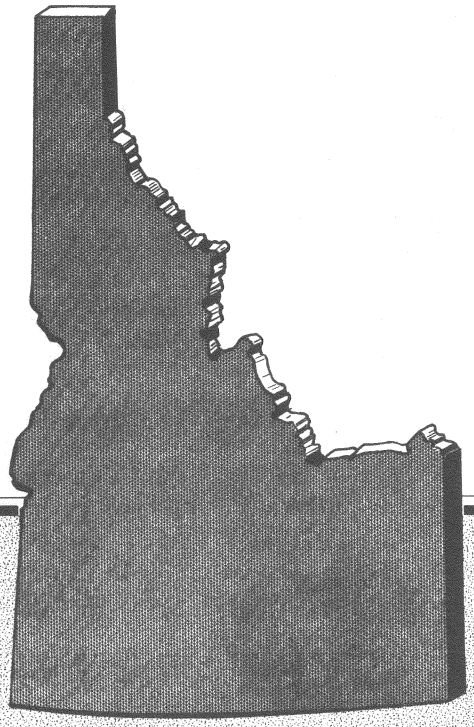
PAVEMENT ROUGHNESS TESTING WITH THE PCA ROADMETER

INITIAL REPORT

ID-H-RP009(2)



JANUARY 1971

RESEARCH PROJECT NO. 9

STATE OF IDAHO DEPARTMENT OF HIGHWAYS

PAVEMENT ROUGHNESS TESTING WITH THE PCA ROADMETER

INITIAL REPORT

L. M. HATCH
Assoc. Research Engineer

January 1971

Idaho Department of Highways
Boise, Idaho

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Introduction

The Department has purchased a PCA Roadmeter as an aid in making pavement condition surveys to help Maintenance in determining priorities for performing major surface maintenance or overlay projects and for testing the roughness of newly constructed pavements. This type roughometer is desirable because testing can be accomplished at 50 mph, or other speeds within the speed limit, allowing considerable roadway to be tested in a short time with little or no disruption of traffic.

In September 1969 the Department obtained the use of the BPR Roughometer to measure the surface roughness of US-20 from its junction with US-20 (the AEC Jct.) to Idaho Falls. The AEC had requested this information and participated in the cost.

The BPR Roughometer is a machine which has been used for several years by many agencies. It is a single wheel trailer which is towed behind a vehicle at 20 mph during testing. Since this machine was available we decided to test additional highways in southern Idaho and compare results with the PCA Roadmeter.

Operation of Equipment

The PCA Roadmeter measures continuously the number and magnitude of deviations between the rear axle and frame of the test vehicle as it travels over the roadway at 50 mph. This measurement is recorded in 1/8 inch increments on high speed electric counters.

Test sections of one mile or less are generally used with the values corrected to one mile for the shorter or longer sections. Tests are normally run on alternate mile sections to permit the data to be recorded. It, therefore, requires two runs to test the complete roadway if sections less than the full length being tested are to be used in an analysis. Investigations by other states of the operating characteristics of the PCA Roadmeter have resulted in recommendations that there be two persons in the front seat during testing, the driver and a recorder to provide a safe operation and to speed up testing by recording data without having to stop the vehicle.

DH-500 4-'65

STATE OF IDAHO
DEPARTMENT OF HIGHWAYS

Intra-Department
Correspondence

To: ALL DISTRICT ENGINEERS **Date:** November 19, 1971

From: MATERIALS AND RESEARCH DIVISION **By:** C. B. Humphrey
C. B. HUMPHREY, P. E.
Materials Engineer

Subject: PCA Roadmeter Test **Project:**

Attached are the results of recent PCA Roadmeter Tests on projects in districts one, two and three. The interpretation of the readings is as follows:

Readings in Counts/Mile

0 - 250	Very Smooth
250 - 500	Smooth
500 - 1000	Slightly Rough
1000 - 2000	Rough
2000 +	Very Rough

It appears from the attached data that all the projects are "very smooth".

We have found a slight dampening effect on the PCA Roadmeter on a plus grade whereas the minus grade seems to increase or exagerate the roughness. This is shown on the first sheet of the data for the 4% grade on the Colton Lane - Virginia project. You will also note that CRCP pavement is rougher than the PCC. Sufficient tests have not been made to form any conclusions about the roughness on grades or on the CRCP versus the PCC.

bjf

cc: ASHE(E) w/enc
ASHE(O) w/enc
Materials and Research Engineer w/enc
Construction Engineer w/enc
Surveys and Plans Engineer w/enc

Conclusions

After about a year's experience with the PCA Roadmeter the following conclusions are made:

1. The PCA Roadmeter data differentiates sufficiently between smooth and rough surfaces to adequately describe the riding quality of a pavement.
2. The PCA Roadmeter is capable of good repeatability at all ranges of roughness.
3. The summation of the roughness count per mile is a simple, direct measurement of the surface smoothness. Without direct correlation with the Chloe Profilometer or a roughometer that has been correlated with the Chloe there is no benefit in making an attempt to derive a formula for a present serviceability rating.

Recommendations

In view of the observed capability of the PCA Roadmeter and certain factors which affect the results it is recommended that:

1. A program of testing be carried out to determine the effects of:

   a. Air temperature
   b. Tire pressure
   c. Number of riders
   d. Full vs. empty gas tank
   e. Rigid vs. flexible pavement
   f. Different drivers
   g. Speed

2. A program of testing statewide be implemented to monitor the depreciation of the pavement surface as an aid in programming projects for resurfacing, reconstruction, etc.
3. A program be implemented to relate the results obtained with the PCA Roadmeter to the Sufficiency Rating being determined by the Planning Survey.

4. Obtain additional Roadmeters, including one which will give a trace of the roughness for the above usages as well as for use with paving projects to obtain better riding surfaces during construction.

5. Two persons be in the front seat during testing. The passenger need not be a trained operator but must be able to record the data quickly. Safety provisions as well as good results require full attention of the driver to driving, while the rider serves as recorder.

6. Based on the curve of Figure 8 the following tentative rating system be adopted for the testing of Idaho highways with the PCA Roadmeter:

Roughness Count	Adjective Rating
0 - 250	Very Smooth
250 - 500	Smooth
500 - 1000	Slightly Rough
1000 - 2000	Rough
over - 2000	Very Rough

Results

One of the first uses made of the PCA Roadmeter was to correlate its results with those obtained with the BPR Roughometer. After testing the AEC Highway the Roughometer was used to test many miles of highway in southern Idaho. These same miles were tested with the PCA Roadmeter. Some were also tested with the Idaho "Bumpometer". The comparison of these tests are shown in the figures which follow. Figure 1 shows the relationship between the results of the BPR Roughometer and the PCA Roadmeter from tests on US-20 east of Idaho Falls run in both the westbound and eastbound lanes on September 4, 1969. These data are in Inches per mile and ΣCount per mile for the Roughometer and Roadmeter respectively. Figure 2 relates the results of the September 4 Roughometer test with a July 2, 1970 PCA Roadmeter test run in the westbound lane only. The regression curves and equations in these figures clearly show a correlation between results.

There is not as good a correlation shown in Figure 3, which represents all the other tests obtained in the comparison of the two pieces of equipment. It is believed that the "wild" points are due more to the poor adjustment of the Roadmeter micro switch than to inaccuracy of the Roadmeter.

A few miles of highway which had been tested with the Roughometer and Roadmeter were also tested with the Idaho Bumpometer before it was dismantled. The Idaho Bumpometer delivered a trace of the movement of both axle ends relative to the body of the vehicle. This type of data is very desirable as you can locate on the roadway the exact rough spot shown on the trace. The disadvantage of the Bumpometer was the time required to read the trace and convert it to useful data.

Figure 4 is a plot of the results obtained with the Idaho Bumpometer, comparing results with the BPR Roughometer by plotting both against the PCA Roadmeter. The trend follows the Roughometer generally, but the numerical values in inches per mile are much smaller. This could be accounted for in the reading of the trace which was quite faint in some instances.

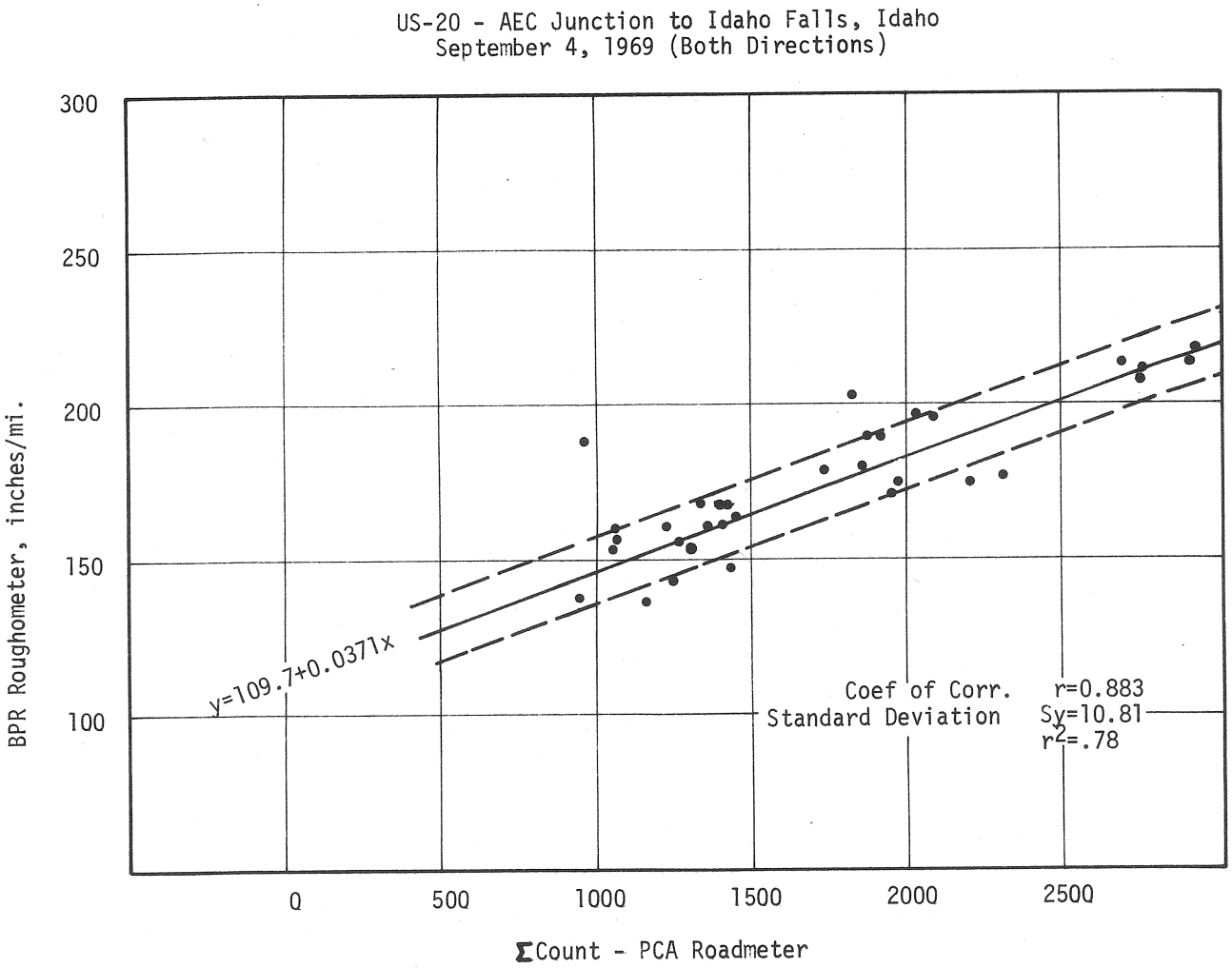

FIGURE 1 — RELATIONSHIP BETWEEN THE RESULTS OF ROUGHNESS TESTING USING THE BPR ROUGHOMETER AND THE PCA ROADMETER.

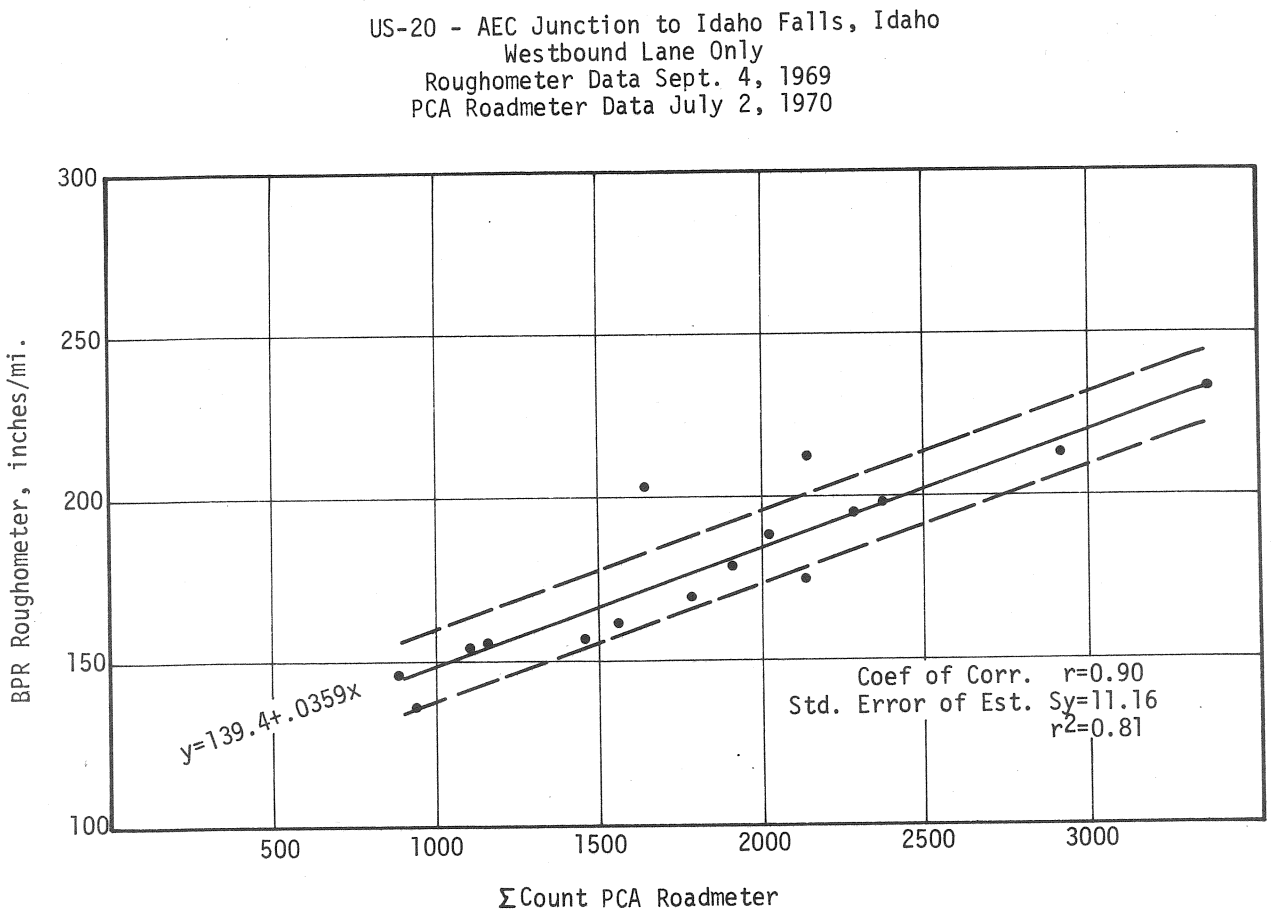

FIGURE 2 – RELATIONSHIP BETWEEN THE RESULTS OF ROUGHNESS TESTING USING THE BPR ROUGHOMETER AND THE PCA ROADMETER.

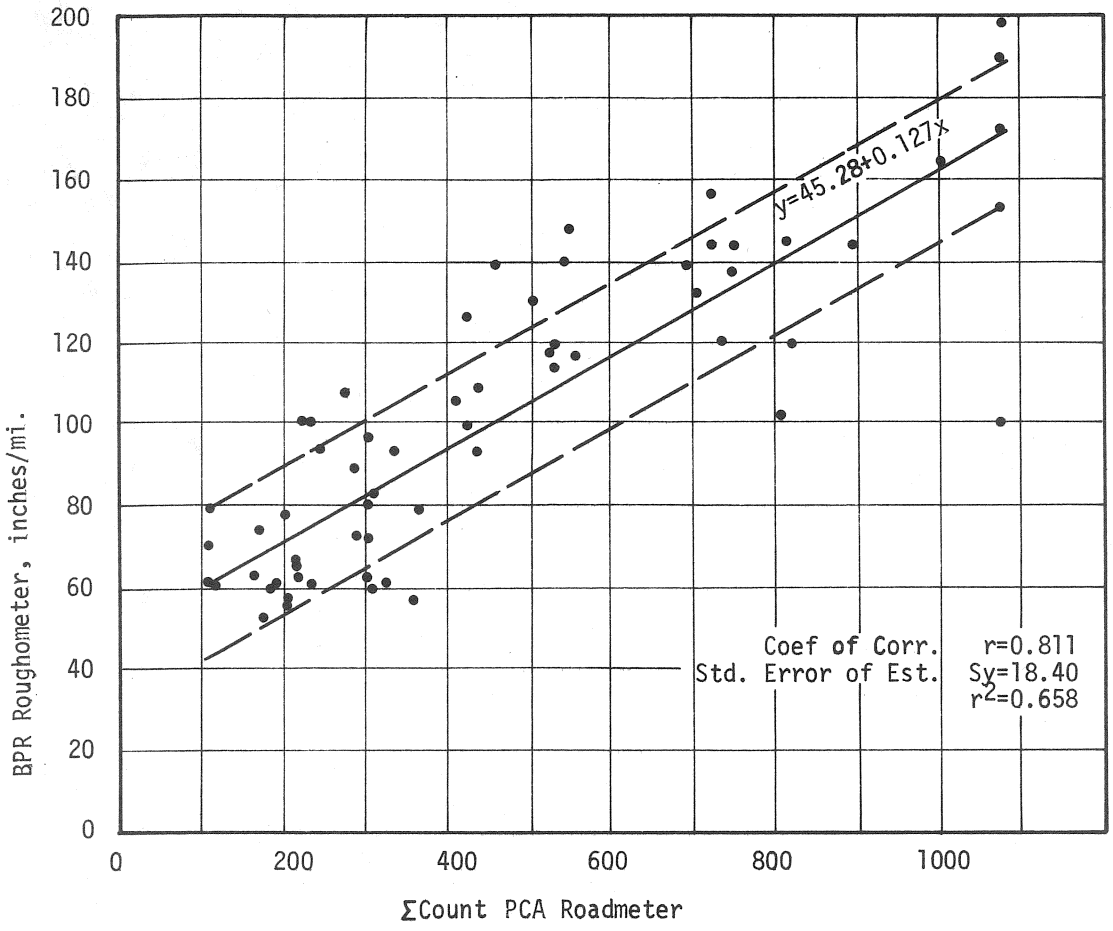

FIGURE 3 — RELATIONSHIP BETWEEN THE RESULTS OF ROUGHNESS TESTING USING THE BPR ROUGHOMETER AND THE PCA ROADMETER ON VARIOUS HIGHWAYS IN SOUTHERN IDAHO.

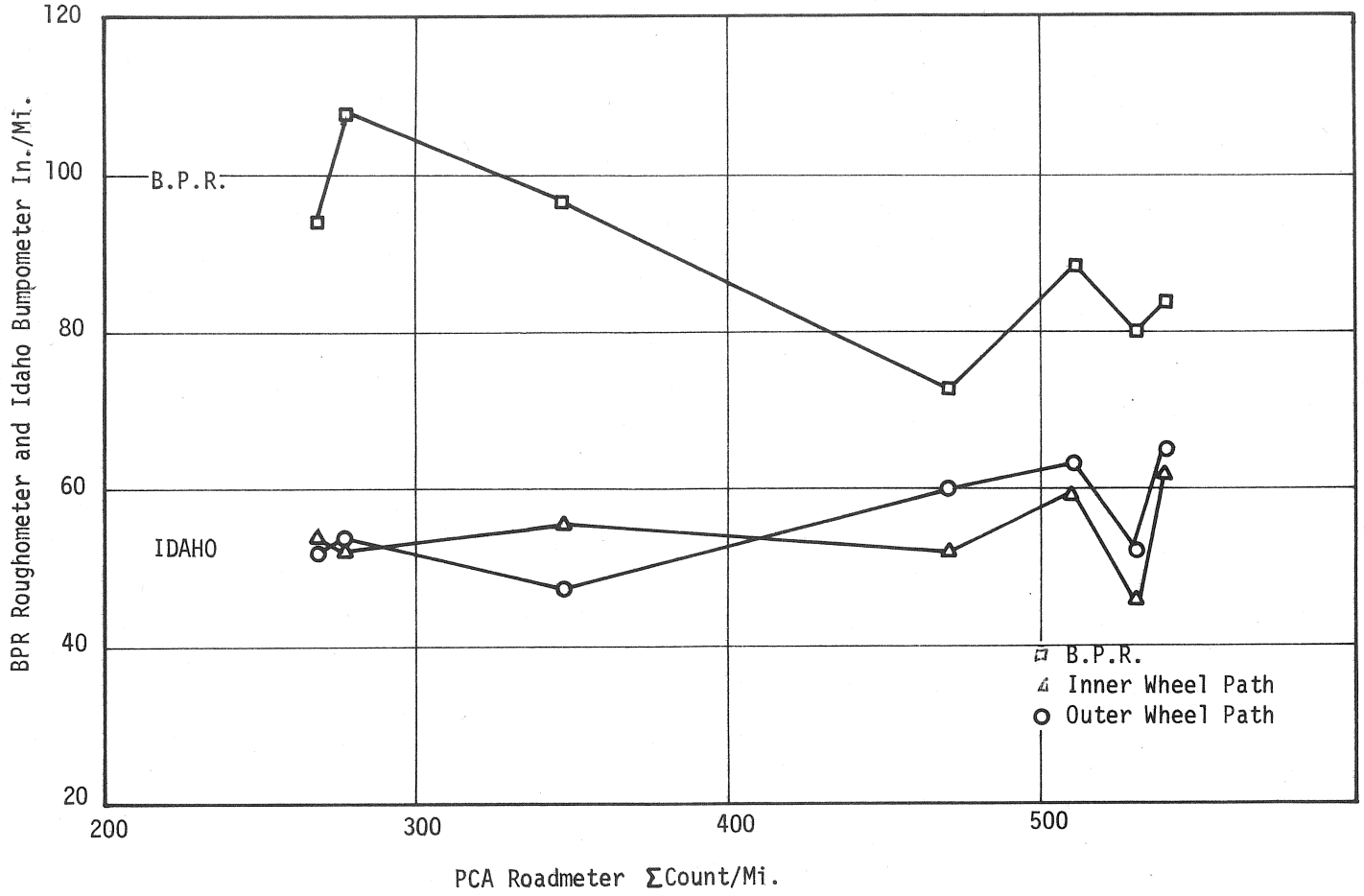

FIGURE 4 - RELATIONSHIP BETWEEN THE PCA ROADMETER RESULTS AND THE BPR ROUGHOMETER, AND THE IDAHO BUMPOMETER.

When the Bumpometer test data is plotted against the Roughometer test data there is the relationship shown in Figure 5. Excluding the two outlying tests the outer wheelpath data gives a general trend in its relationship with the Roughometer. There is no comparison with the inner wheelpath data. This is probably because the BPR Roughometer was towed in the outer wheelpath of the travelway.

Each District was asked to submit selected road sections rated by them on a scale between Very Smooth and Very Rough or Unsatisfactory on the basis of rideability. These sections were tested with the Roadmeter. A comparison of the results is shown in Figure 6. The disparity between the two ratings is excessive.

It was considered that it might be the Roadmeter that was in error, or that it could not repeat itself. Each test section was run approximately four times each direction to assure accuracy. Each plotted point in Figure 6 is an average of three or four runs with the PCA Roadmeter. The repeatability of the machine is illustrated by the test results of Table 1.

The deviation evident in Figure 6 is due to the inability of raters to adequately equate roughness by driving a vehicle over the road.

During the 1970 paving season several pavements were tested with the Roadmeter during construction as well as on newly completed projects. All results have been reported to the Districts. Since testing is done at 50 mph a minimum of 1/2 mile of finished pavement, and preferrably more, is required for a test.

The results of the testing on the 1970 pavements are listed in Table 2 and compared graphically in Figure 7. Table 3 gives results of nearly every section tested in the State thus far. These include the sections rated and submitted by the Districts for rating the Roadmeter. The frequency distribution of these tests is shown in the ogive curve of Figure 8. This curve indicates that approximately 25% of the sections tested gave results of less than 250 count per mile, approximately 50% gave results of less than 500 count per mile, while approximately 95% had a roughness count of less than 2000 per mile.

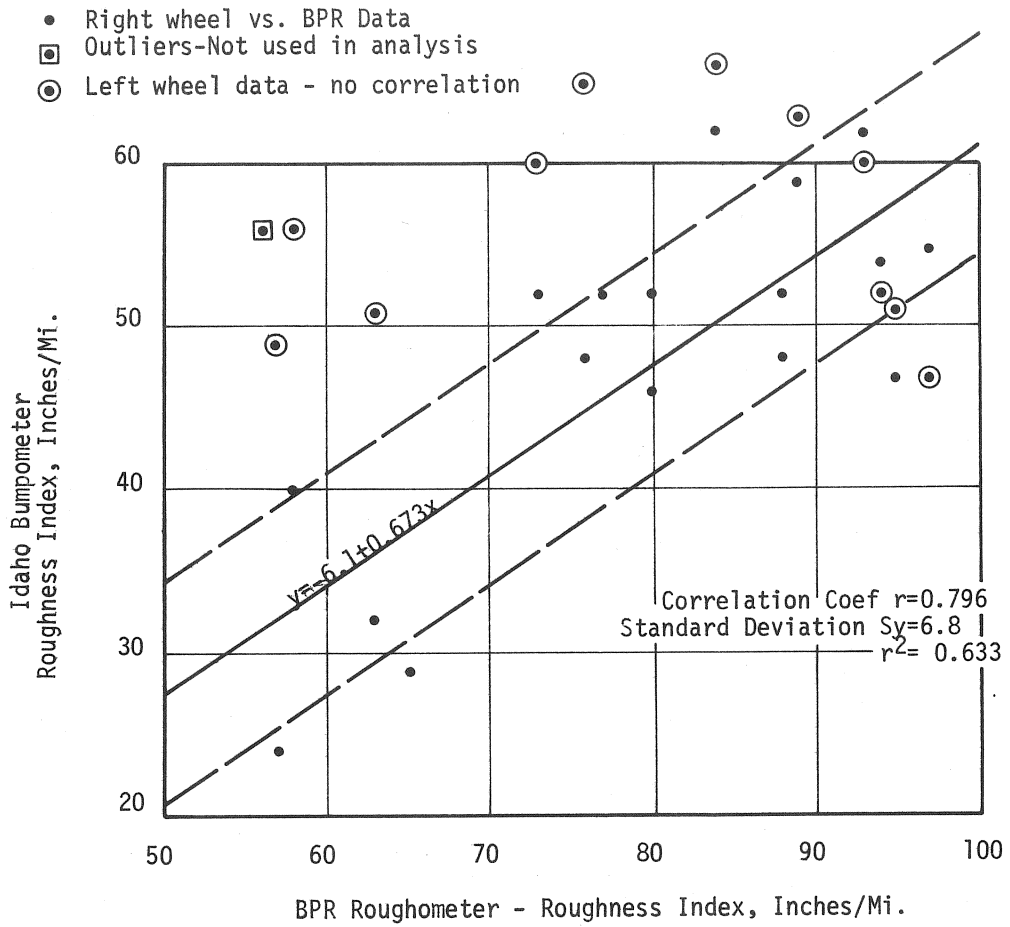

FIGURE 5 – CORRELATION OF RIGHT WHEEL TRACE DATA (IDAHO BUMPOMETER) WITH BPR ROUGHOMETER DATA.

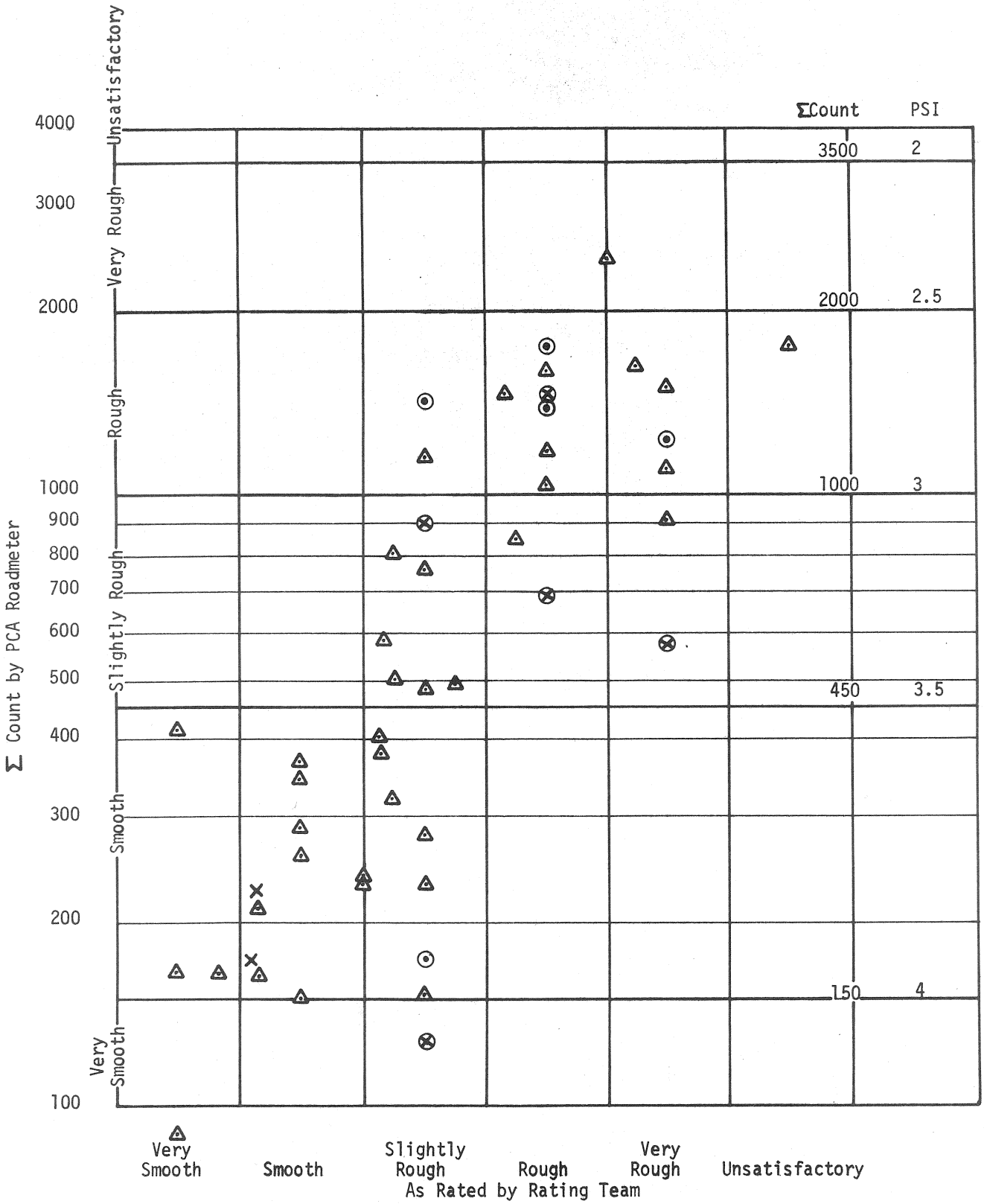

FIGURE 6 – ROAD SURFACE ROUGHNESS RATING – DISTRICT RATING TEAMS VS PCA ROADMETER.

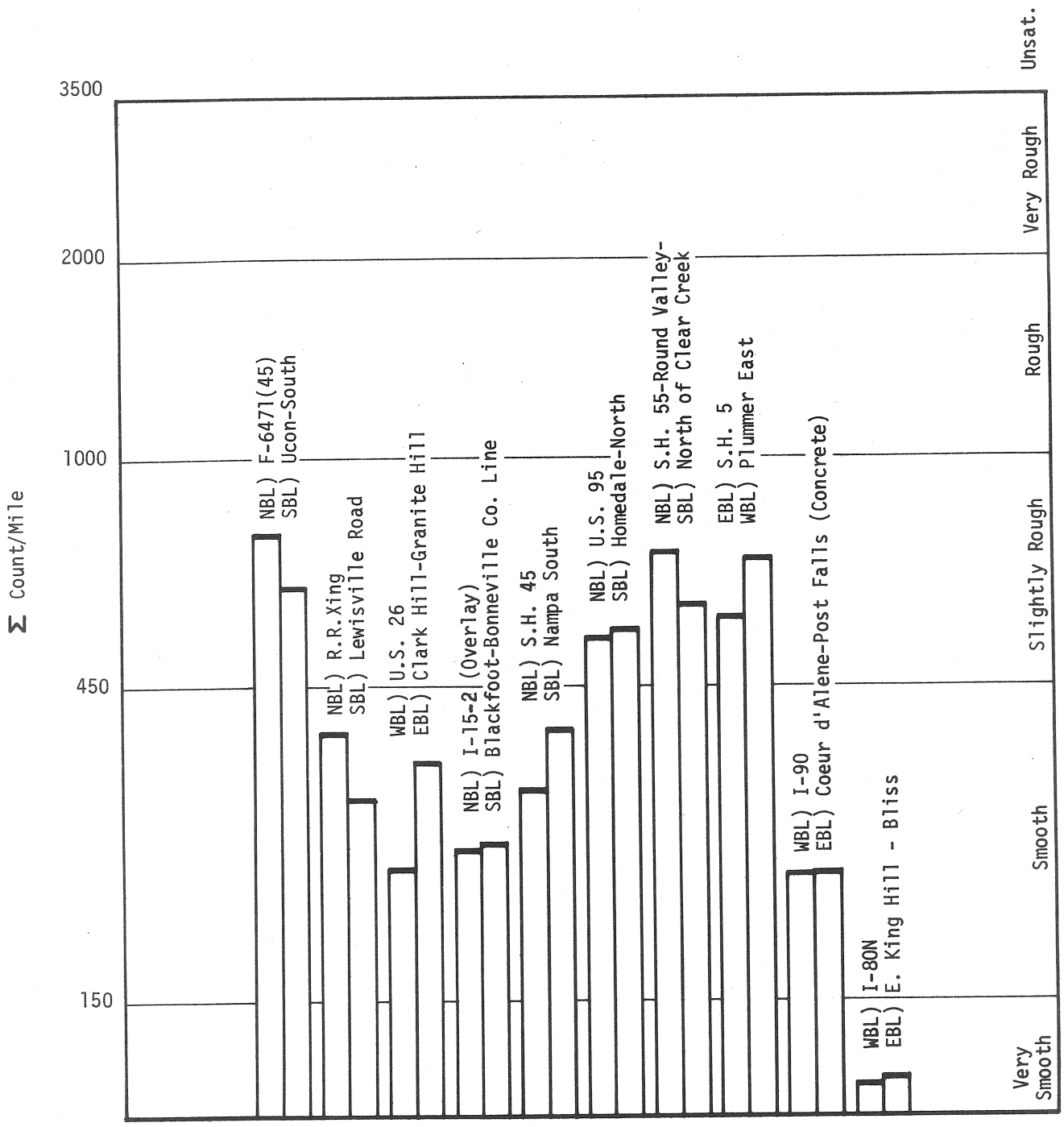

FIGURE 7 – COMPARISON OF SURFACE ROUGHNESS BY PCA ROADMETER ON 1970 CONSTRUCTION AND OVERLAY PROJECTS.

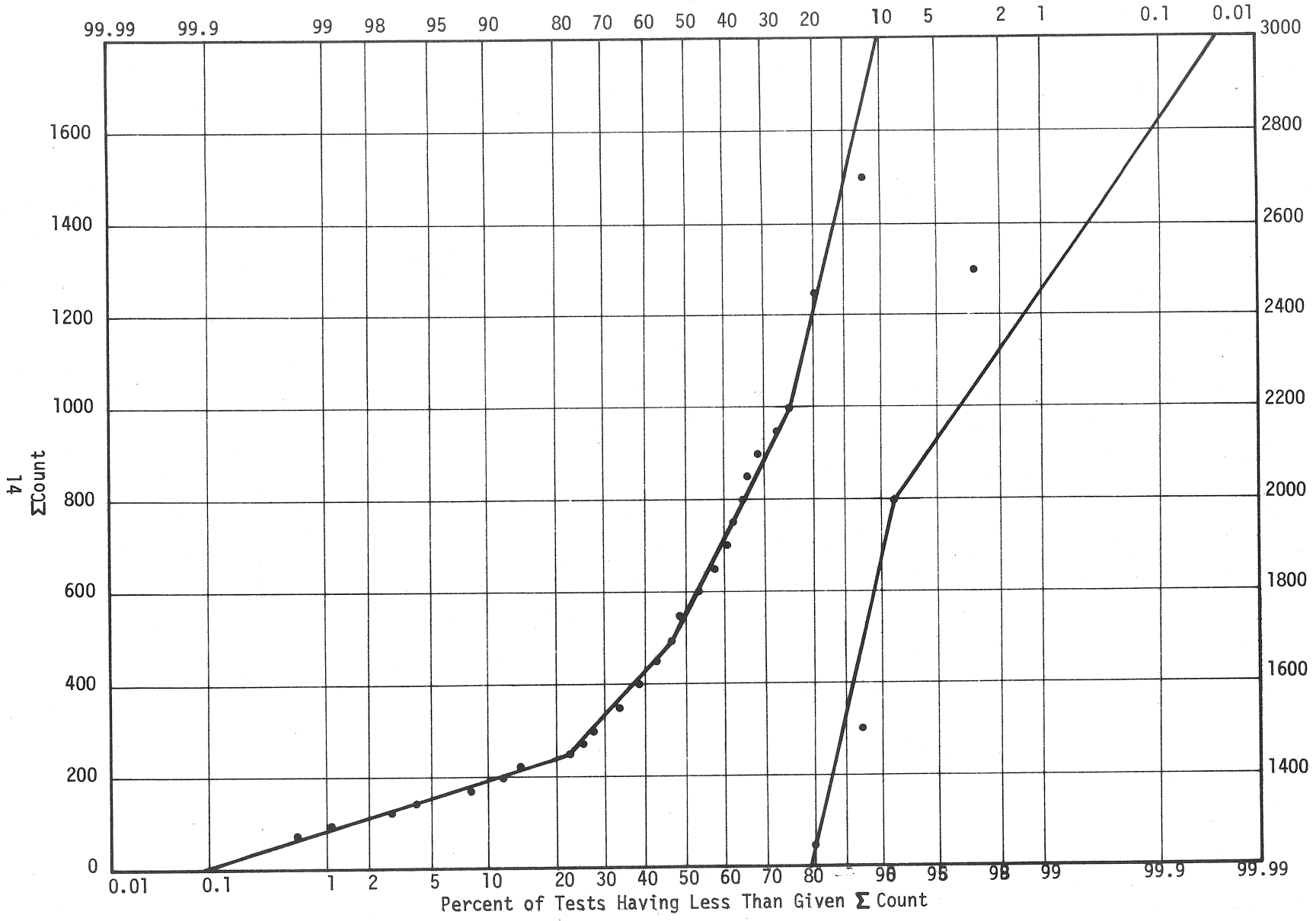

FIGURE 8 - FREQUENCY DISTRIBUTION OF ROUGHNESS TESTS BY PCA ROADMETER.

District 1 Malad - South

MP - 9-10 ΣCount/Mi.

NBL	SBL
3750	2963
2701	2959
2974	3019
2988	2945

District 2 US-26 Shoshone-West

MP - 175 - 176 ΣCount/Mi.

EBL	WBL
556	1053
576	1183
590	1349
595	1379
466	

District 3 - US-20-26

MP 50 - 52 ΣCount/Mi.

EBL	WBL
401	553
409	613
412	546
388	552

District 4 US-12

MP 15 - 17 ΣCount/Mi.

EBL	WBL
942	1474
896	1419
842	1384
919	1478

District 5 Cataldo-Pine Cr. I-90

MP 41.5 - 43 Approx. 1.5 Miles
ΣCounts/Mi. Rated Very Smooth

WBL	EBL
394	399
405	405
399	403

District 6 Idaho Falls-Bassett
I-15-3 M.P. 124 - 125
Very Smooth Rating on SBL
ΣCount/Mi.

NBL	SBL
209	90
200	95
222	95
237	

Table 1 - Repeatability

Project	Milepost	Ave. Σ Count	Range
I-80N-3			
E. King Hill-Bliss	W.B.L.	112	88-146
	E.B.L.	115	63-152
US-26			
Clark Hill-Granite Hill	356-366		
	W.B.L.	239	223-265
	E.B.L.	347	269-418
US-191			
Ucon-Beeches Corner Overlay	S.B.L.	608	522-703
US-191			
RRXing-Lewisville Rd.	N.B.L.	385	350-407
	S.B.L.	303	266-330
SH-45			
Nampa-South	N.B.L.	314	258-398
	S.B.L.	388	375-470
US-95	N.B.L.	534	476-587
Homedale -Wilder Jct.	S.B.L.	550	436-693
SH-55	160-163		
Round Valley	N.B.L.	719	618-816
	S.B.L.	598	581-726
New US-191	N.B.L.	769	430-1487
F-6471(45) Lewisville Rd-Ucon	S.B.L.	639	471-1054
I-15-W	93-112		
Blackfoot-No. Overlay	N.B.L.	256	121-341
	S.B.L.	262	193-322
SH-5			
Plummer East	1-3		
	E.B.L.	568	515-629
	W.B.L.	803	704-910
I-90			
Coeur d'Alene-Post Falls (Concrete)	W.B.L.	233	154-303
	E.B.L.	234	204-275

Table 2 - 1970 Paving Projects

District 1

ΣCount/Mile - PCA Roadmeter

Route	Section	MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
		EBL		
US-30	Raft River - Rockland Jct.	251-254	15	2618
		255-262	15	969
		263-276	10	172
		WBL		
		270-263	10	268
		262-257	15	1176
		256-251	15	2229
		SBL		
US-191	Deep Creek - South	16-13	10	1178
		12-11	10	386
		10-9	10	2589
		8-7	5	258
		NBL		
		10-12	10	640
		12-16	10	1160
		SBL		
I-15-1	Deep Creek - Colton Road	21-18	5	321
		NBL		
		17-20	5	250
		NBL		
I-15-1	Inkom - Pocatello	57-60	New	632
		61-64	Pmx.	352
		SBL		
		62-61	1969	227
		SBL		
	Inkom - Arimo	54-47	5	168
		44-41	5	217
		NBL		
	Arimo - Portneuf	40-55	5	237
US-91-191	Virginia - Downey	42-38	5	658
I-15W	American Falls Bypass	279-272	8	244
US-26	Atomic Jct. - Blackfoot	286-301	15	1109

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 2

ΣCount/Mile - PCA Roadmeter

Route	Section	MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
		NBL		
SH-46	Wendell - Gooding	7-8	10	143
		SBL		
		8-7	10	155
		WBL		
US-26	Shoshone - West	176-175	20	1241
		EBL		
		175-176	20	579
		NBL		
SH-46	Wendell - Gooding	3-4	10	117
		SBL		
		4-3	10	68
		WBL		
SH-25	Jerome - US-93	181-180	5	375
		EBL		
		180-181	5	432
		WBL		
US-26	Shoshone, East	182-181	20	1741
		EBL		
		181-182	20	1466
		EBL		
US-26	Gooding-Shoshone	167-168	5	176
		WBL		
		168-167	5	129
		EBL		
US-30	Bliss-Hagerman	152-153	5	165
		WBL		
		153-152		165
US-20-26-93A	Shoshone-Richfield	EBL		
		181-195	20	930
		EBL		
US-20-26	Gooding-Shoshone	163-172	5	197
		175-178	5	986

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 2

ΣCount/Mile - PCA Roadmeter

Route	Section	MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
		WBL		
US-20-26-93A	Arco-Crater of the Moon	259-252	20	2076
		251-244	20	985
		EBL		
	Craters of the Moon - Arco	242-250	20	855
		251-261	20	1621
US-20-26	Butte City - AEC Junction	268-269	15	674
		270-279	15	1162
		280-285	15	2161
		SBL		
US-93	Shoshone - South	73-60	5	763
		NBL		
		59-73	5	911
		NBL		
US-93	Shoshone - North	75-80	20	967
		82-92	10	895
		SBL		
		92-82	10	849
		83-76	20	799
		EBL		
I-80N	Salt Lake I.C.-Cotterell	233-240	8	282
		WBL		
		240-234	8	224
	Salt Lake I.C.-Heyburn I.C.	233-219	8	270
	Burley I.C.-West(Ch.Seal)	217-206	5	242
	(Pmx. Seal)	201-185	5	248
	Jerome-SH 50 I.C. (Pmx. Seal)	178-191	5	182
	Greenwood-Burley (Ch.Seal)	206-219	5	201
	Cotterell-Utah State Line	247-286	New	107
	Utah State Line-Cotterell	286-245	New	117
SH-27	Paul-Burley S.B.	26-24	8	340

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 3

ΣCount/Mile - PCA Roadmeter

Route	Section		MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
I-80N	Meridian - Maple Grove (Conc.)		45-48	15	570
	Boise Bypass-(Conc.)	EBL	50-57	1	553
		WBL	55-50	1	525
	Boise - Mountain Home	EBL	72-81	5	265
		WBL	78-71	5	170
		WBL	100-86	5	420
	Meridian, West		44-29	5	238
	Caldwell to Oregon S.L.	WBL	28-27	5	839
			26-0	5	226
	Oregon S.L. to Caldwell	EBL	0	5	172
SH-69	Kuna-Meridian	NBL	0-6	20	539
		SBL	9-2	20	490
SH-55	Boise West Connector (Conc.)	WBL	62-61	1	522
		EBL	60-63	1	686
	Marsing - Nampa	EBL	31-40	20	480
		WBL	41-30	20	486
	Jct.w/44 - Summitt	NBL	102-111	20	638
SH-44	Caldwell - Boise	EBL	33-55	10	377
		WBL	50-32	10	319
SH-52	Horseshoe Bend - Emmett	WBL	53-52	20	473
			51-49	20	612
			43-42	20	936
			40-39	20	475
			35-34	20	723
	Emmett-Gottschalk Corner		28-17	15	696
SH-21	Boise-Lucky Peak	NBL	3-14	15	508
	Lucky Peak - Boise	SBL	10-5	20	572
Old US-30	Boise - East	EBL	64-67	20	927
	Meridian - Boise	EBL	54-59	5	200
		WBL	59-54	5	286

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 3

ΣCount/Mile - PCA Roadmeter

Route	Section		MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
SH-19	Wilder - Caldwell	EBL	18-9.5	20	602
US-95	Payette - Gayway Jct.	SBL	69-67	1	490
US-95	Payette - North	NBL	71-74	1	234
			74-71	1	334
US-30	Snake River - Gayway Jct.	EBL	0.10-0.6	1	426
		WBL	0.43-0.10	1	612
SH-16	Emmett - Jct. SH-44	SBL	31-44	5	341
US-30	Mountain Home - East	EBL	104-107	20	1410
		EBL	108-119	20	875
	Star Road	NBL		5	349
		SBL		5	338
US-20-26	West of Boise	EBL	50-52	20	397
		WBL	52-50	20	573
		EBL	52-53	20	869
		WBL	53-52	20	736
US-30	Mountain Home - East	EBL	104-105	20	1454
		WBL	105-104	20	1839
		EBL	105-106	20	2188
		WBL	106-105	20	2712
		EBL	106-106.5	20	1205
		WBL	106.5-106	20	1040
SH-21	Boise - Lucky Peak	NBL	8-9	20	404
		SBL	9-8	20	579
		NBL	9-10	20	445
		SBL	10-9	20	571
			12-13	20	367
SH-44	West of Eagle		45-46	5	238
			46-48	5	291
			49-50	5	233

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 4

ΣCount/Mile - PCA Roadmeter

Route	Section		MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
US-12	East of Spaulding	EBL	15-17	20	901
		WBL	17-15	20	1439
US-95	Lawyers Canyon		280-282	20	1473
	No. of Moscow	WBL	373-378	20	764
		SBL		20	937
	Fenn. N & S		257-260	20	382
	Nez Perce Co. Line		296-298	5	578
US-12	Spaulding Br. - West		11-12	5	236

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 5

ΣCount/Mile - PCA Roadmeter

Route	Section		MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
I-90	Cataldo - Pine Creek	EBL	41.5-43	5	402
		WBL	43 -41.5	5	421
	Kellogg-Osburn(Conc.)	EBL	56-58	New	797
		WBL	58-56	New	749
	Wallace - Mullan (Conc.)	EBL	64-68	5	902
		WBL	68-64	5	1320
	Smelterville - Kellogg	EBL	48.8-52.3	5	312
		WBL	52.3-48.8	5	265
US-95A	St. Maries - Mission Point	NBL	434-435	20	1710
		SBL	435-434	20	1446
US-95	Moctilene-Plummer	NBL	407-408	20	1694
		SBL	408-407	20	1848
	Latah Co. Line - Tensed	NBL	394-395	20	1373
		SBL	395-394	20	972

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

District 6

ΣCount/Mile - PCA Roadmeter

Route	Section		MP-MP	Approx. Age in Years	Ave. All Readings ΣCount/Mi.
I-15	Bassett - Roberts (new)	NBL	129-136	New	320
		SBL	136-129	New	389
	Idaho Falls - Bassett				
	Idaho Falls - Bassett	NBL	121-128	5	189
US-26	Beaches Corner - Ririe	EBL	337-338	10	281
		WBL	338-337	10	230
	Ririe - Clark Hill		347-348	New	231
US-191	South of Rexburg	NBL	152-153	20	683
		SBL	153-152	20	1410
SH-28	East of Terreton		162-163	10	167
I-15-3	Idaho Falls - Bassett	NBL	124-125	5	217
		SBL	125-124	5	93
US-191	Ucon - Rigby		139-140	10	606
I-15-3	Bassett - Roberts (1 yr.)		129-136	New	189
US-191	Idaho Falls - Shelley	NBL	119-122	20	2262
		SBL	122-119	20	1890
		SBL	118-115	20	467
		NBL	114-117	20	324
		NBL	124-125	20	2340
US-26	AEC Jct. - Idaho Falls	EBL	286-297	15	1459
			297-304	15	2375
			304-323	15	1342
		WBL	323-304	15	1371
			304-297	15	2842
			297-286	15	1834

Table 3 - Roughness Tests Performed Using the PCA Roadmeter

The Maintenance Engineer has expressed an interest in the Roadmeter as a means of determining priorities for maintenance projects. He suggested that for the sake of interest certain sections of roadway be tested, even though some of these were already being prepared for overlay contracts. Figures 9-13 have been plotted so as to be easily compared. Most of these have sections rating "Very Rough" on the scale being used, i.e. Count per mile above 2000.

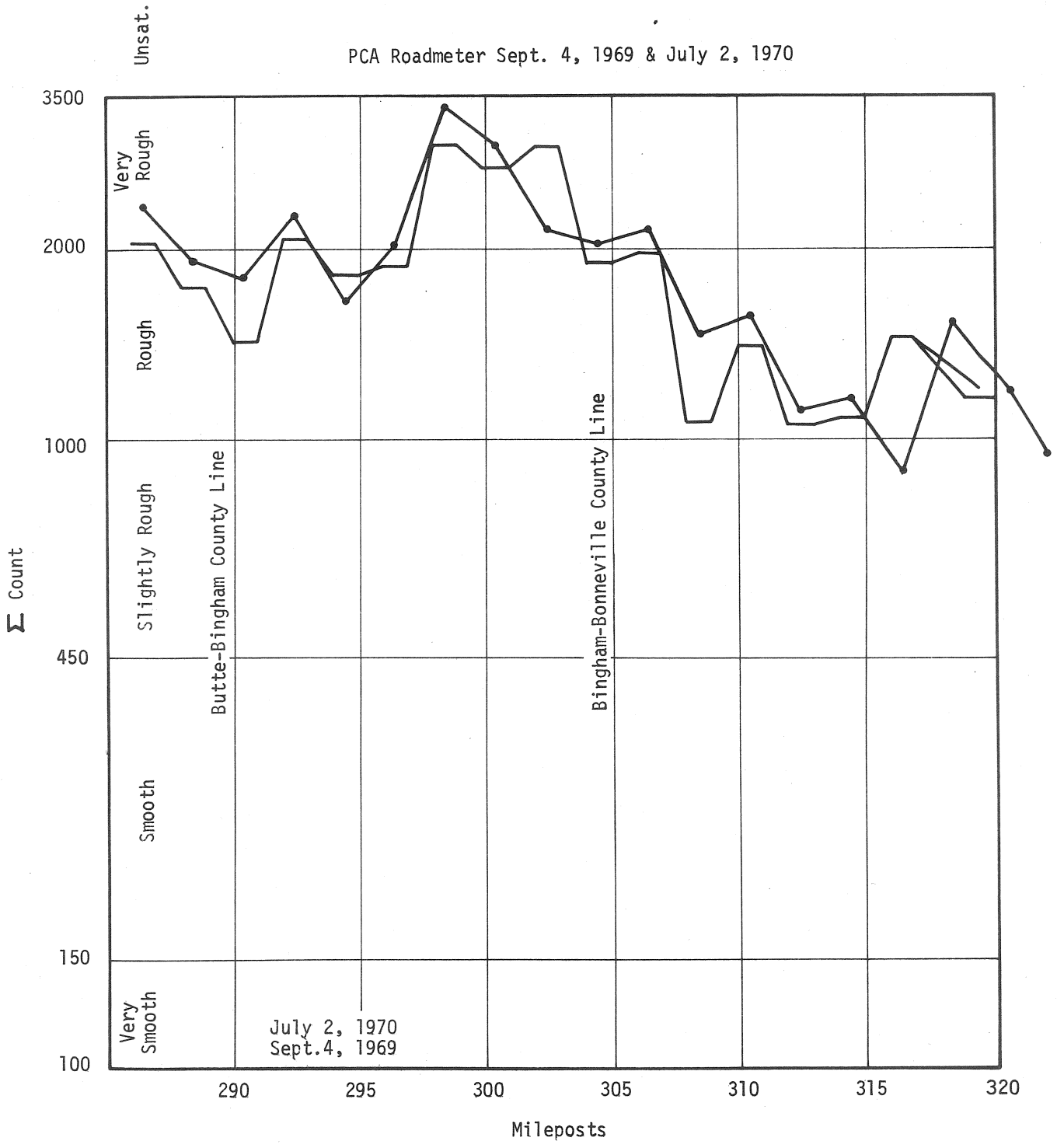

FIGURE 9 - COMPARISON OF PAVEMENT ROUGHNESS ON WESTBOUND LANE US 20 - IDAHO FALLS TO AEC JUNCTION.

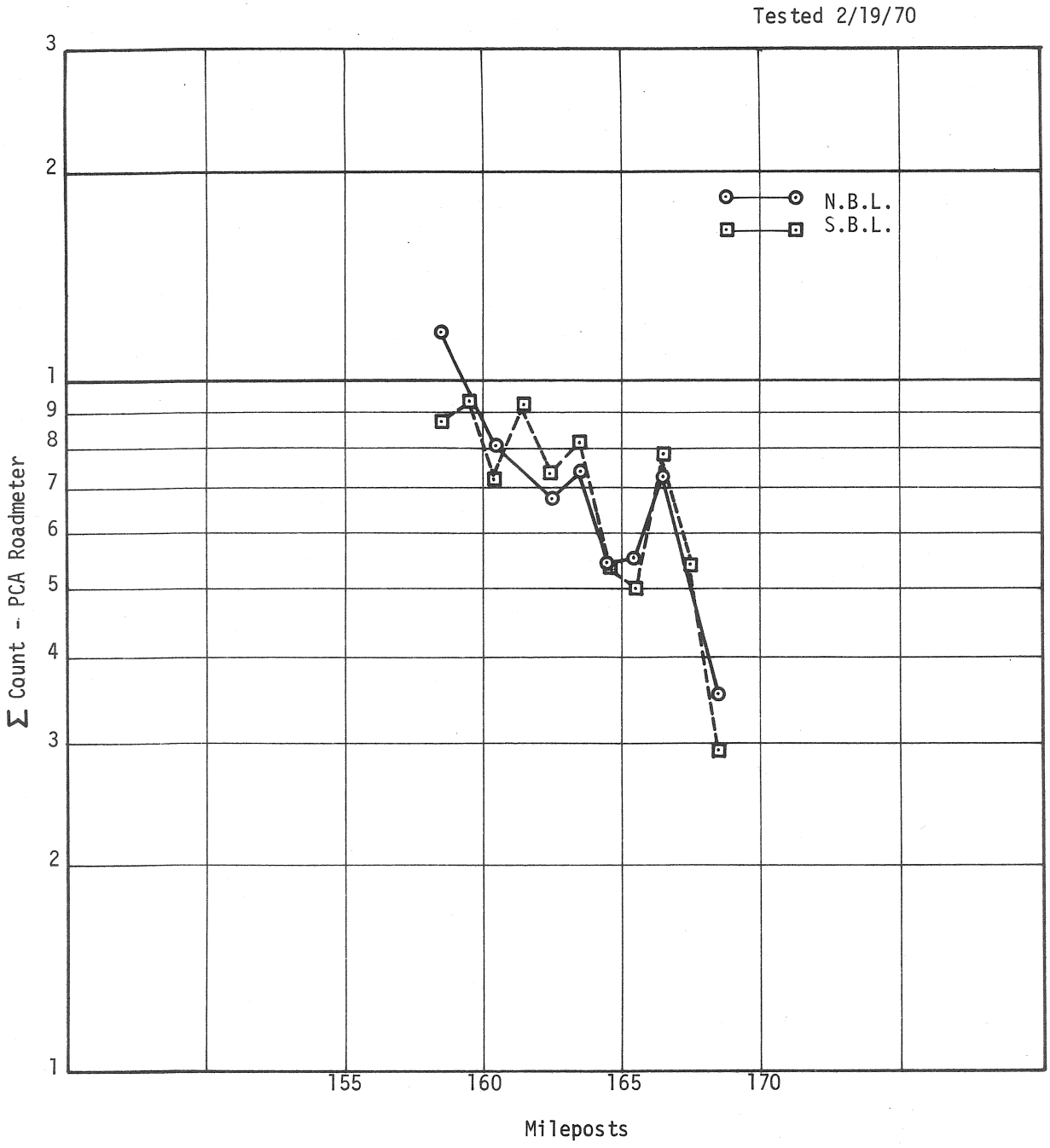

FIGURE 10 – ROUGHNESS TESTING FOR MAINTENANCE – SH 55 ROUND VALLEY.

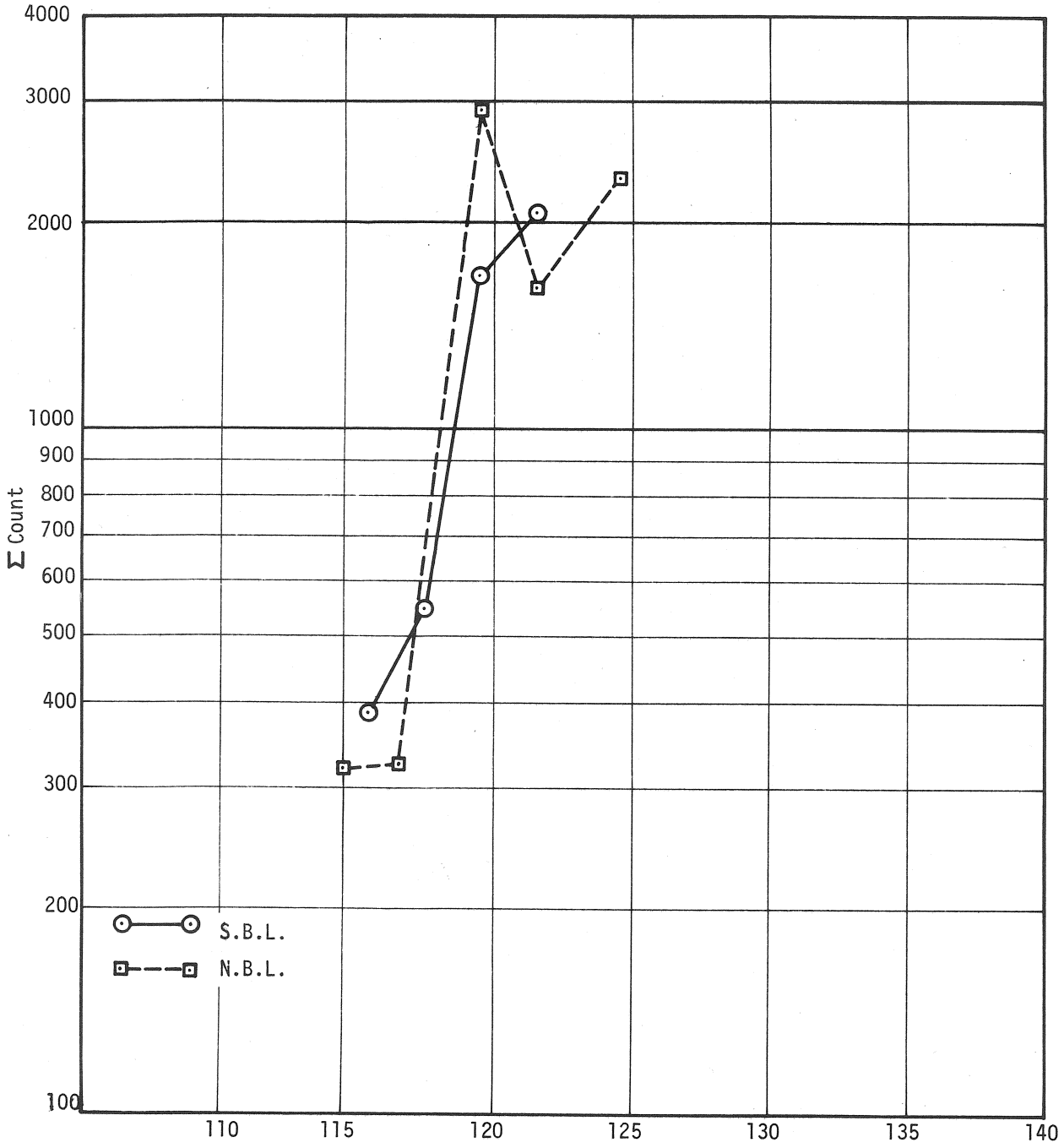

FIGURE 11 – ROUGHNESS TESTING FOR MAINTENANCE
U.S. 191 – SHELLEY N&S.

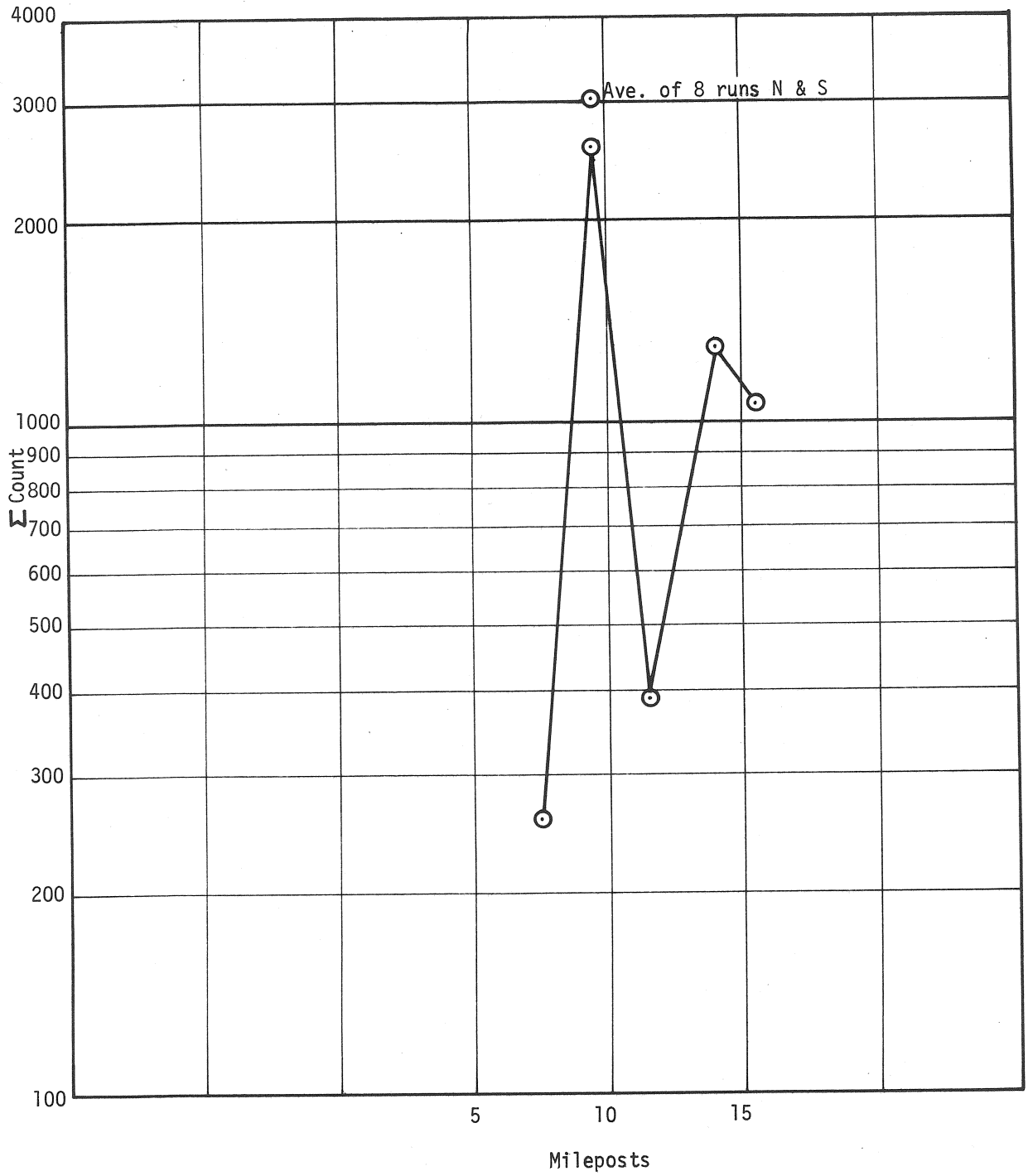

FIGURE 12- ROUGHNESS TESTING FOR MAINTENANCE
U.S. 191 - MALAD SOUTH - SBL.

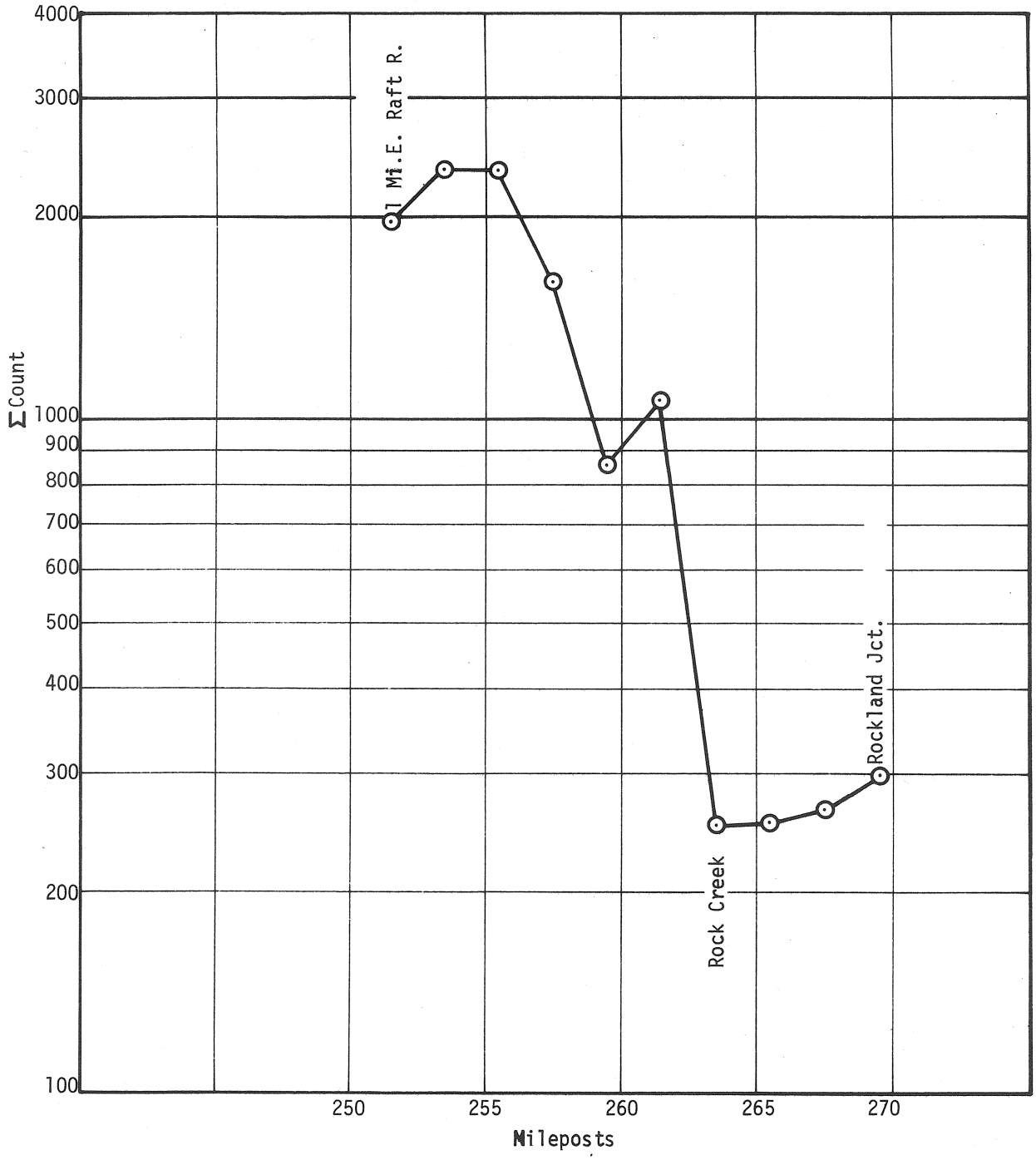

FIGURE 13 – ROUGHNESS TESTING FOR MAINTENANCE
U.S. 30 - RAFT RIVER - ROCKLAND JCT. WBL.

Other Testing

Roadmeter operating instructions state that tire pressures should be maintained at 30 psi. One test was run where two to four passes were made each direction on a given mile of highway with pressures at 45#, 35# and 30#. The average count at each pressure each direction are shown in Table 4 below.

Pressure	Σ Count/Mi. (Ave.)	
	EBL	WBL
45	472	360
35	432	345
30	432	322

Table 4 - Affect of Tire Pressure

On the basis of this one test, run at an air temperature of approximately 80°F., it seems that a pressure within a pound or two of the recommended would not affect the results seriously.

Tests were run at several sites at several different speeds. It is desirable to correlate results of different operating speeds since it may not always be possible to make a test at the recommended speed of 50 mph, especially in a restricted speed zones. The results of this testing are not too definitive at some of the speeds run. Figures 13-17 show the results for tests at 20,30,35,40 and 60 mph, compared to the results at 50 mph. Additional testing is necessary to better define the relationship.

I checked with Lee Hatch to see whether the 30psi is measured with tires cool or warm. He has been checking pressure cold & we will continue this way.
ajt sept. '73

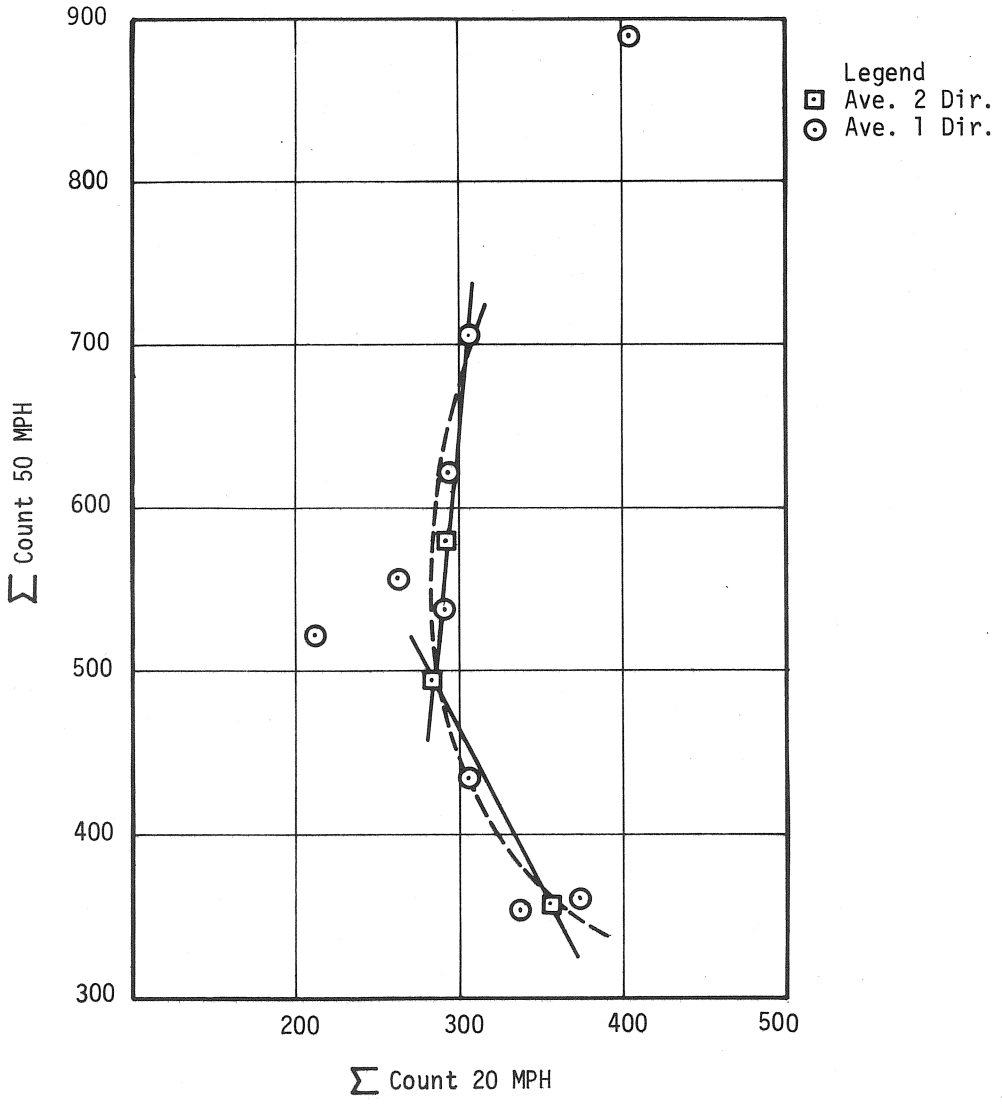

FIGURE 14 – VARIABLE SPEED STUDIES 20 MPH VS 50 MPH.

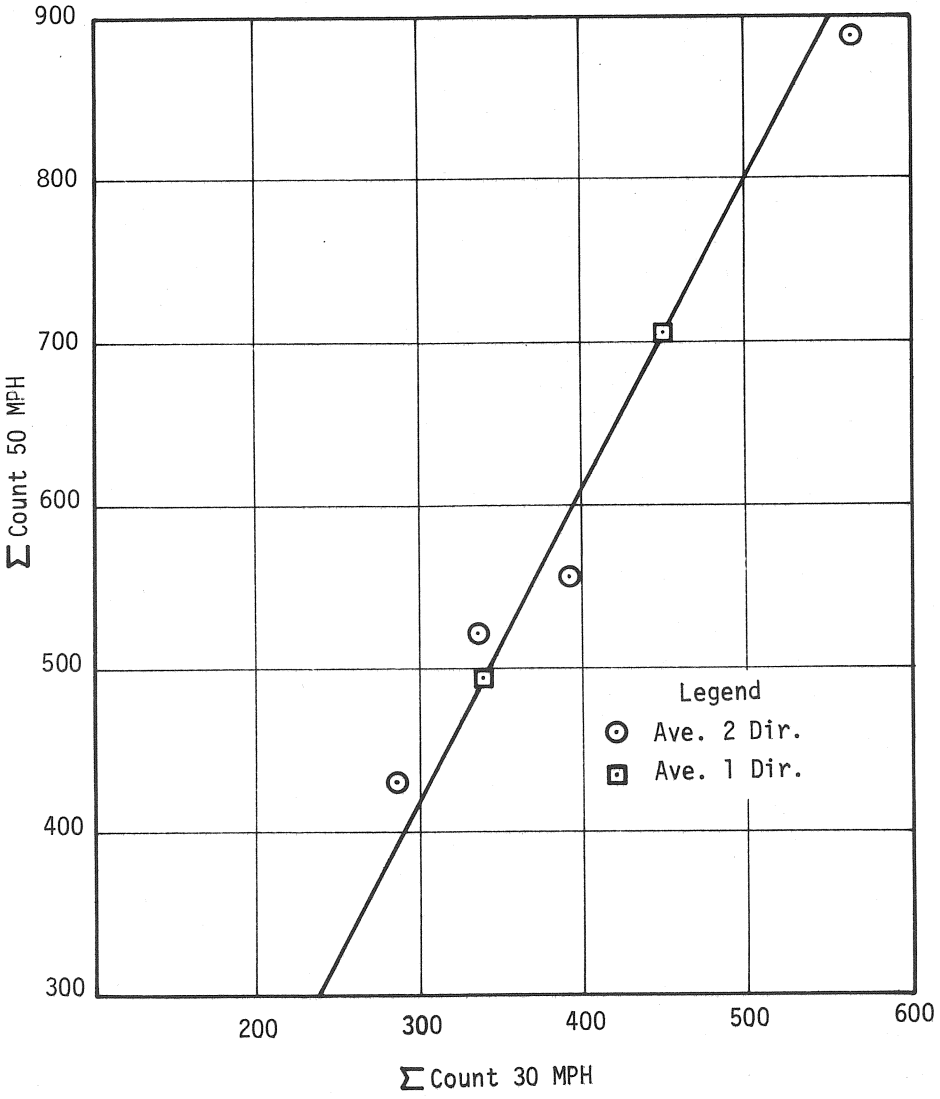

FIGURE 15 - VARIABLE SPEED STUDIES - 30 MPH VS 50 MPH.

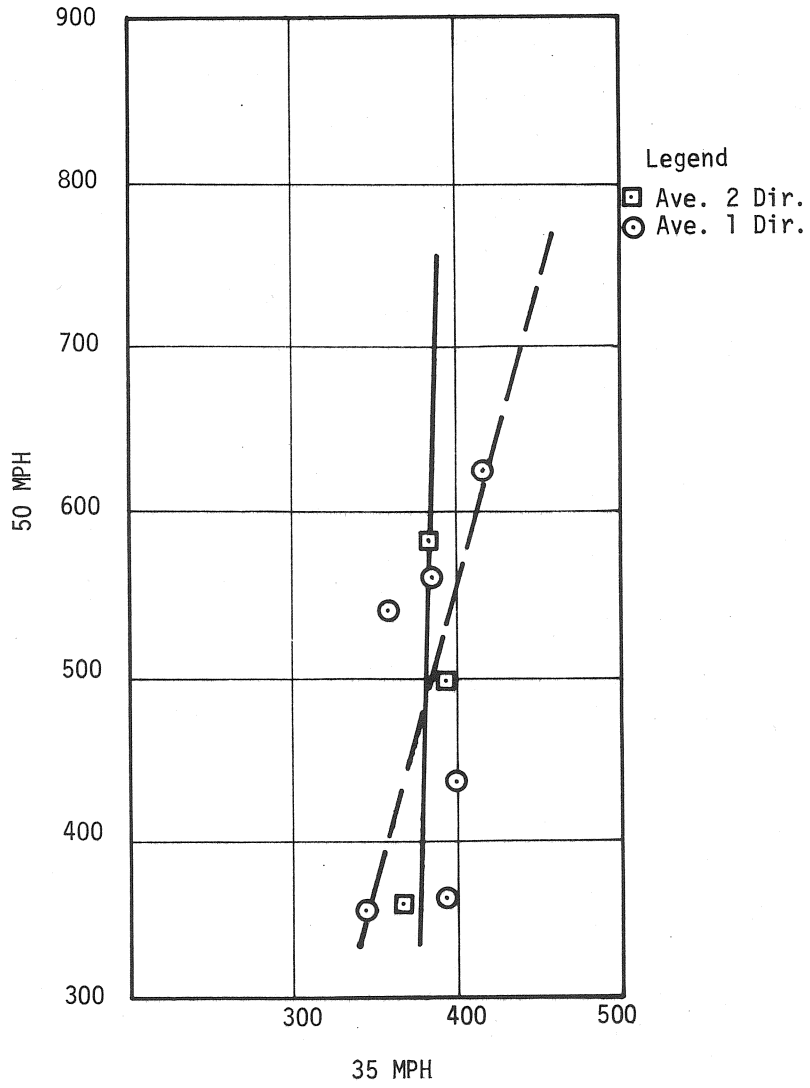

FIGURE 16 – VARIABLE SPEED STUDIES – 35 MPH VS 50 MPH.

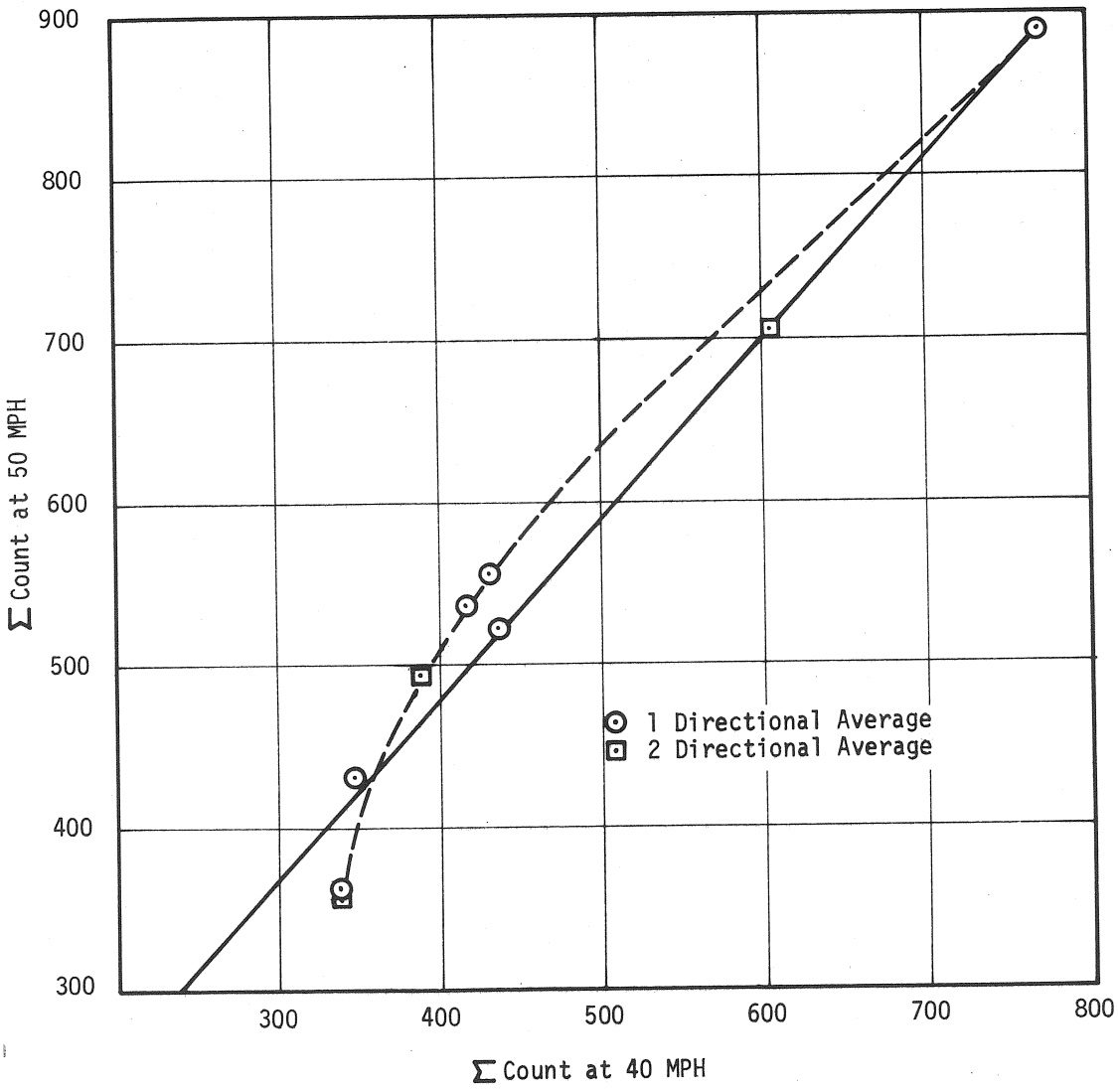

FIGURE 17- VARIABLE SPEED STUDIES - 40 MPH VS 50 MPH.

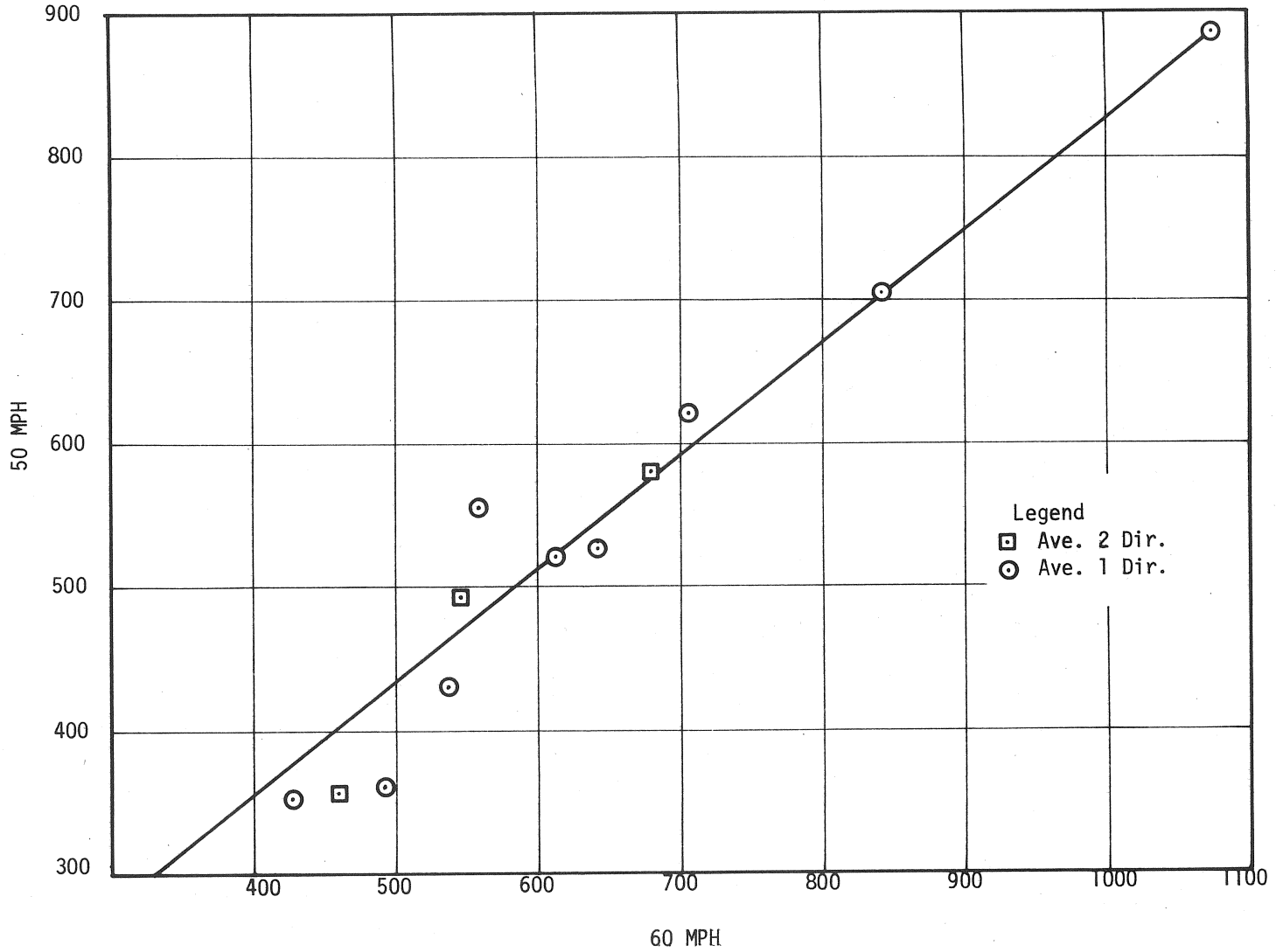

FIGURE 18 – VARIABLE SPEED STUDIES – 60 MPH VS 50 MPH.